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Wentink

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(54) **SYMMETRIC TRANSMIT OPPORTUNITY (TXOP) TRUNCATION**

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(60) Provisional application No. 60/757,827, filed on Jan. 10, 2006, provisional application No. 60/735,024, filed on Nov. 8, 2005, provisional application No. 60/758,595, filed on Jan. 11, 2006.

(51) **Int. Cl.**

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H04W 74/08	(2009.01)
H04W 28/04	(2009.01)
H04W 84/12	(2009.01)
H04W 92/10	(2009.01)

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CPC ***H04W 28/12*** (2013.01); ***H04N 21/4126*** (2013.01); ***H04W 74/08*** (2013.01); ***H04W 74/0816*** (2013.01); ***H04W 74/0866*** (2013.01); *H04W 28/04* (2013.01); *H04W 84/12* (2013.01); *H04W 92/10* (2013.01)

(58) **Field of Classification Search**
CPC . H04N 21/4126; H04W 28/04; H04W 28/12; H04W 74/08; H04W 74/0816; H04W 74/0866; H04W 84/12; H04W 92/10
See application file for complete search history.

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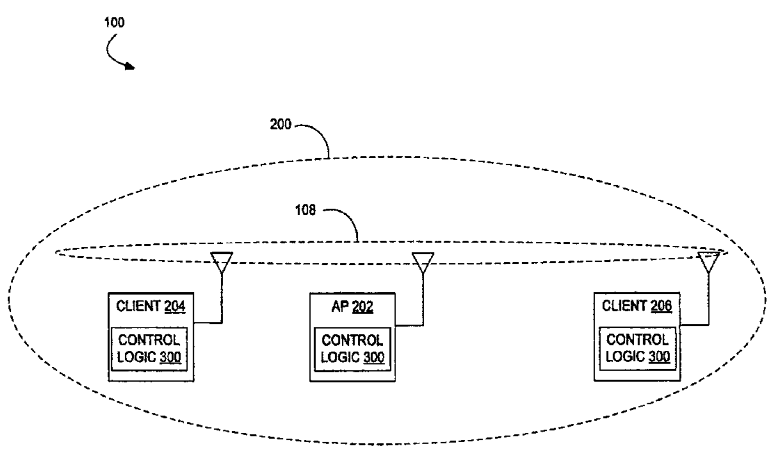
Primary Examiner — Kashif Siddiqui

(57) **ABSTRACT**

Various embodiments of symmetric transmit opportunity (TXOP) truncation (STT) systems and methods are disclosed. One method embodiment, among others, comprises receiving a frame that truncates a TXOP around a first station, and responsive to receiving the frame, sending a second frame that truncates the TXOP around a second station. Others system and method embodiments are disclosed.

20 Claims, 16 Drawing Sheets



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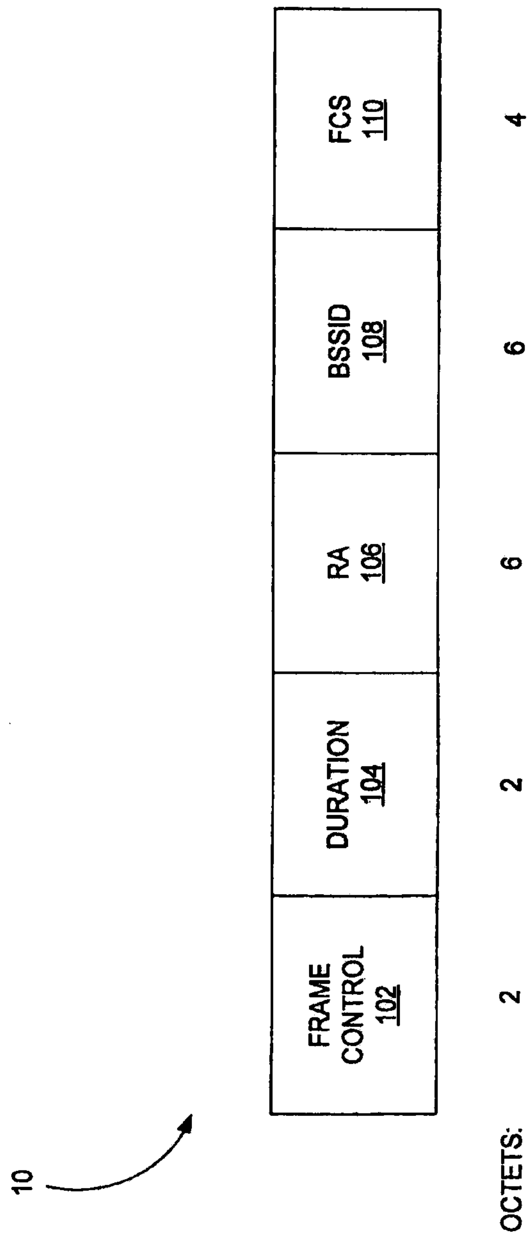

FIG. 1 (PRIOR ART)

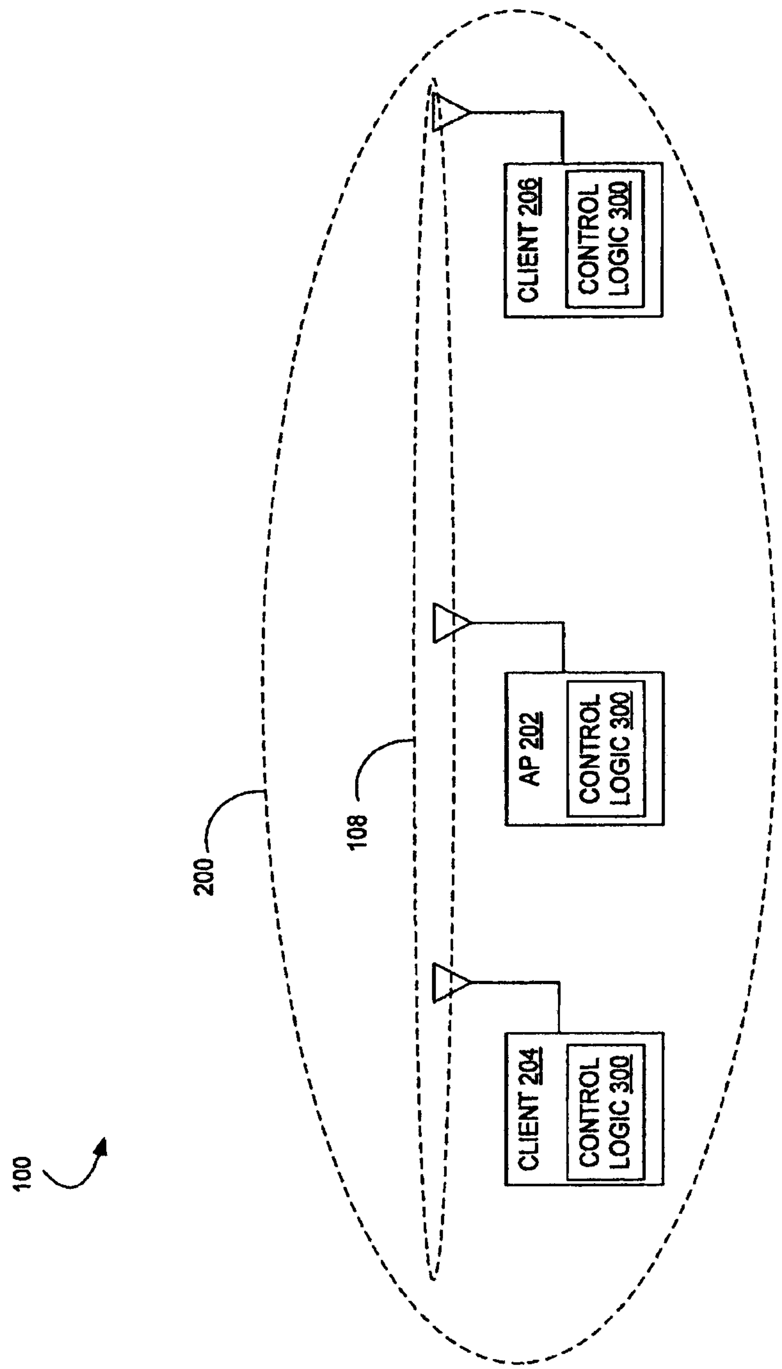
CLIENT 206
CONTROL LOGIC 300
AP 202
CONTROL LOGIC 300
CLIENT 204
CONTROL LOGIC 300
108
200
100

FIG. 2

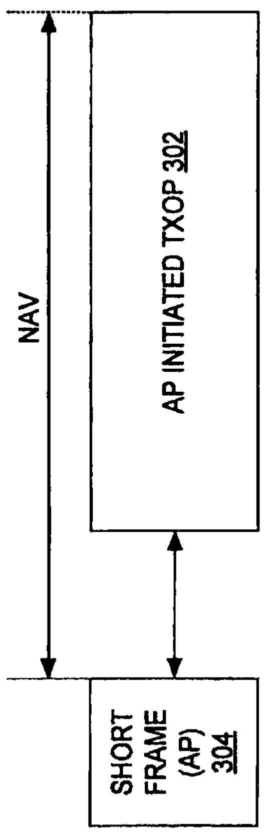
NAV
AP INITIATED TXOP 302
SHORT FRAME (AP) 304

FIG. 3A

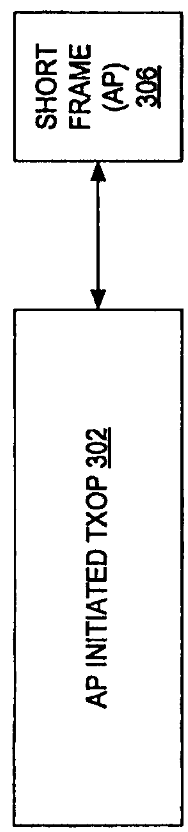
SHORT FRAME (AP) 306
AP INITIATED TXOP 302

FIG. 3B

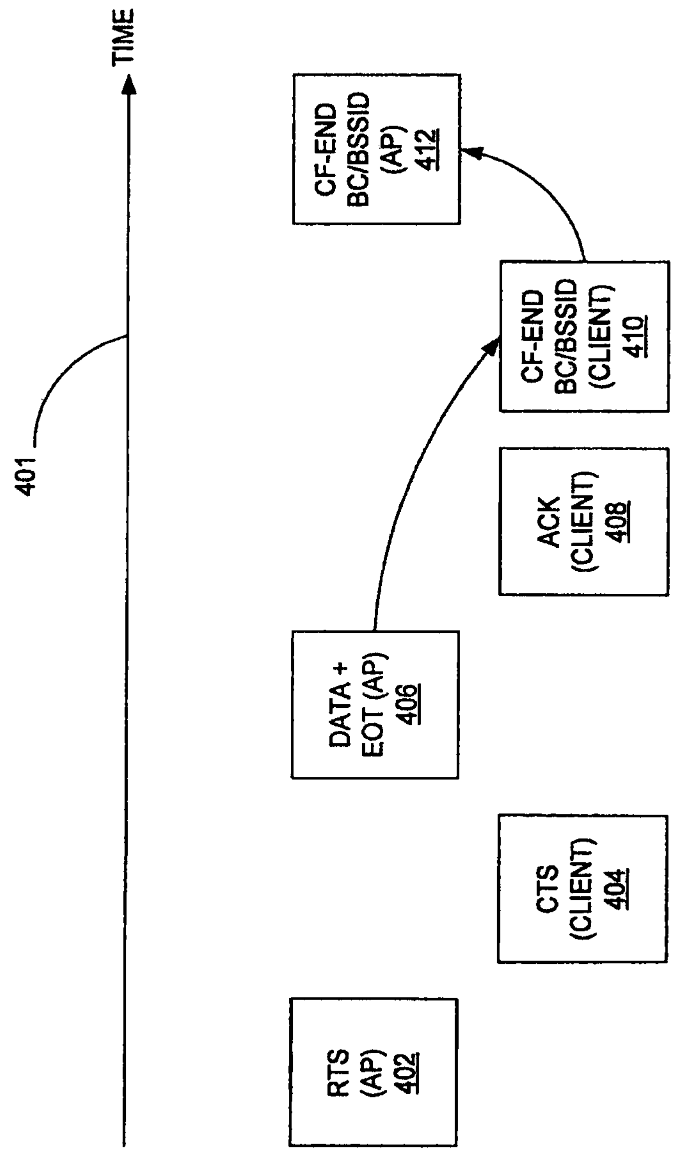
TIME
401
RTS
(AP)
402
CTS
(CLIENT)
404
DATA +
EOT (AP)
406
ACK
(CLIENT)
408
CF-END
BC/BSSID
(CLIENT)
410
CF-END
BC/BSSID
(AP)
412

FIG. 4

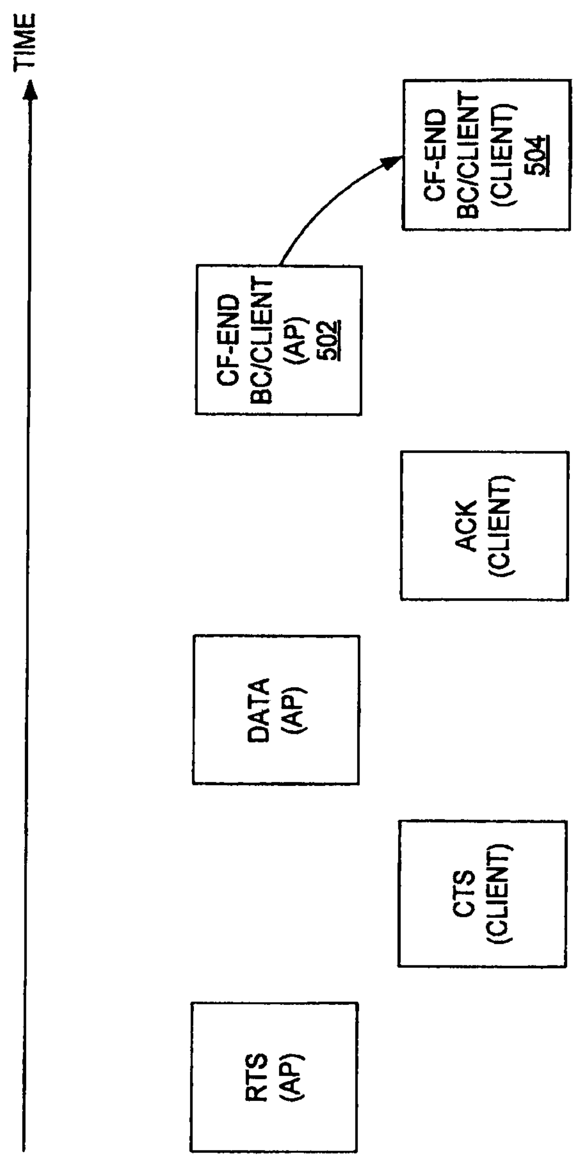
TIME
RTS (AP)
CTS (CLIENT)
DATA (AP)
ACK (CLIENT)
CF-END BC/CLIENT (AP) 502
CF-END BC/CLIENT (CLIENT) 504

FIG. 5

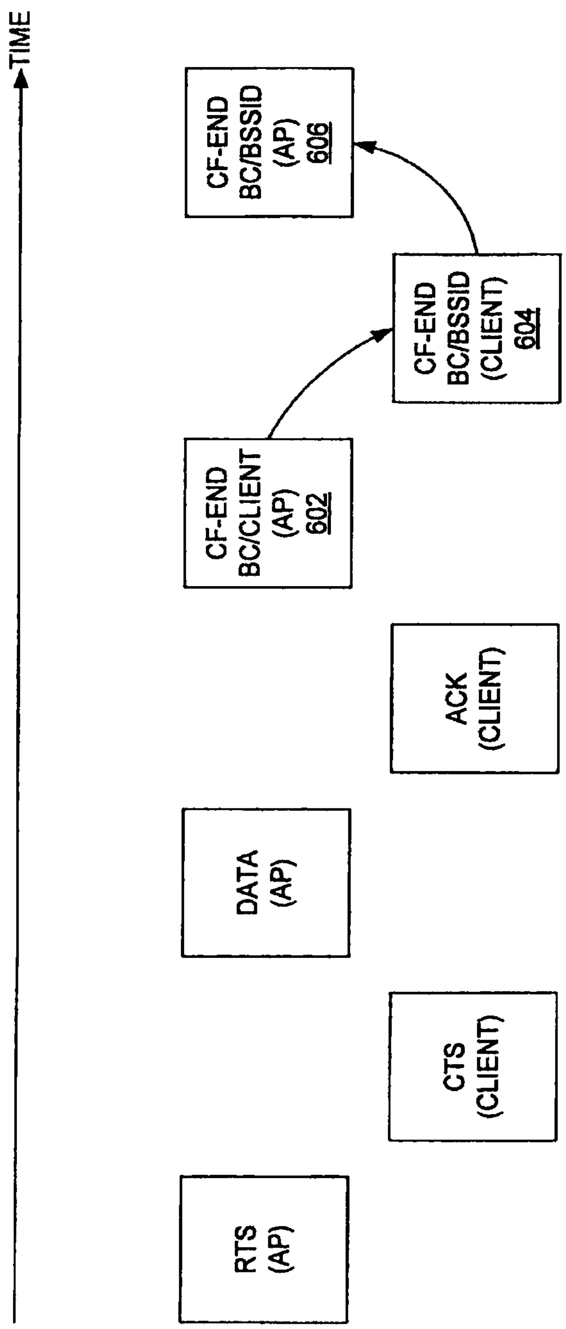
TIME
RTS (AP)
CTS (CLIENT)
DATA (AP)
ACK (CLIENT)
CF-END BC/CLIENT (AP) 602
CF-END BC/BSSID (CLIENT) 604
CF-END BC/BSSID (AP) 606

FIG. 6

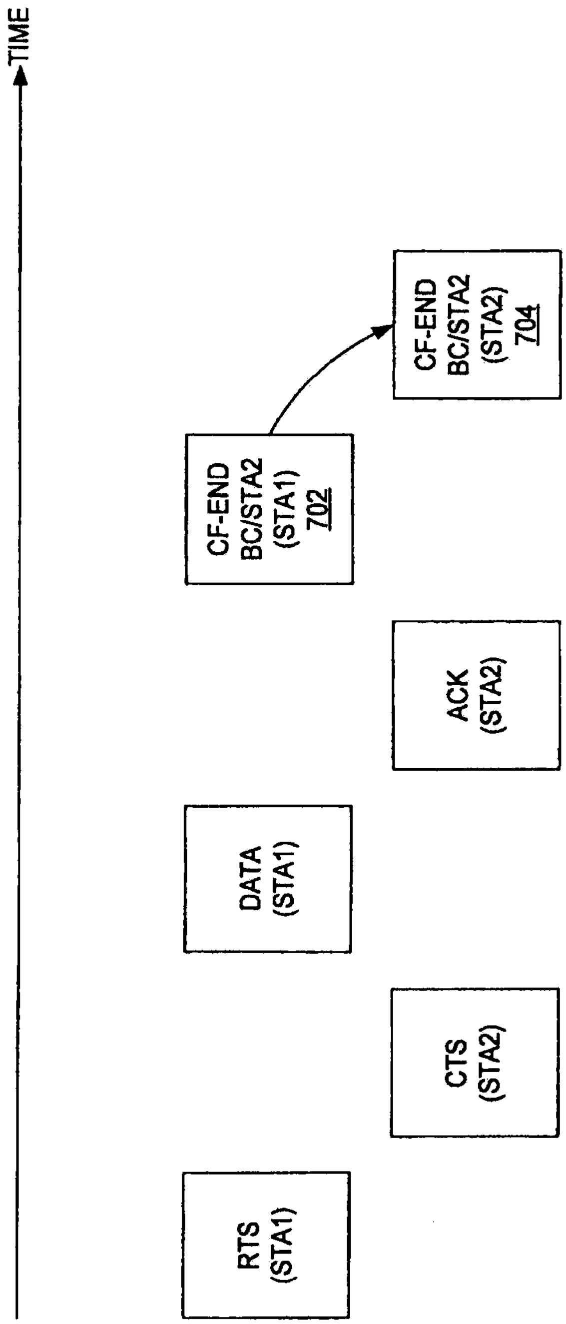
TIME
RTS (STA1)
CTS (STA2)
DATA (STA1)
ACK (STA2)
CF-END BC/STA2 (STA1) 702
CF-END BC/STA2 (STA2) 704

FIG. 7

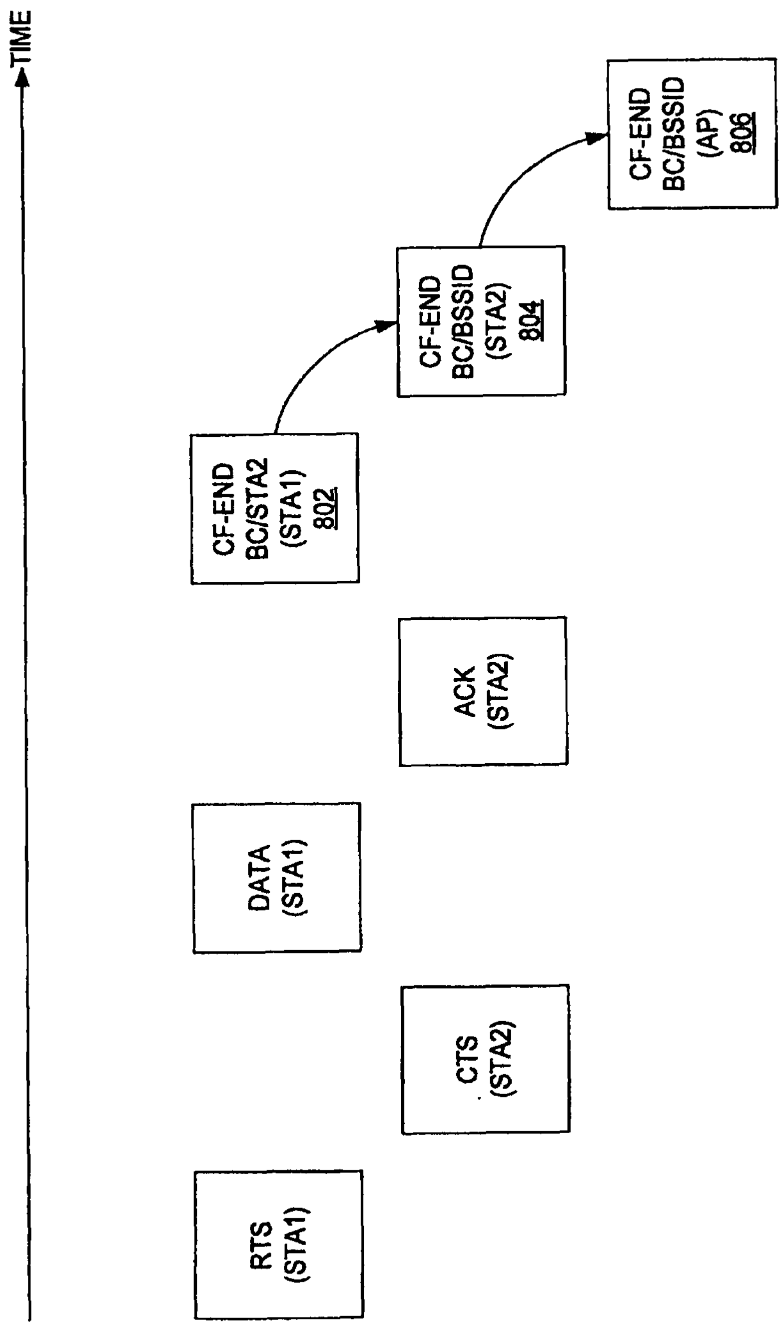
TIME
RTS (STA1)
CTS (STA2)
DATA (STA1)
ACK (STA2)
CF-END BC/STA2 (STA1) 802
CF-END BC/BSSID (STA2) 804
CF-END BC/BSSID (AP) 806

FIG. 8

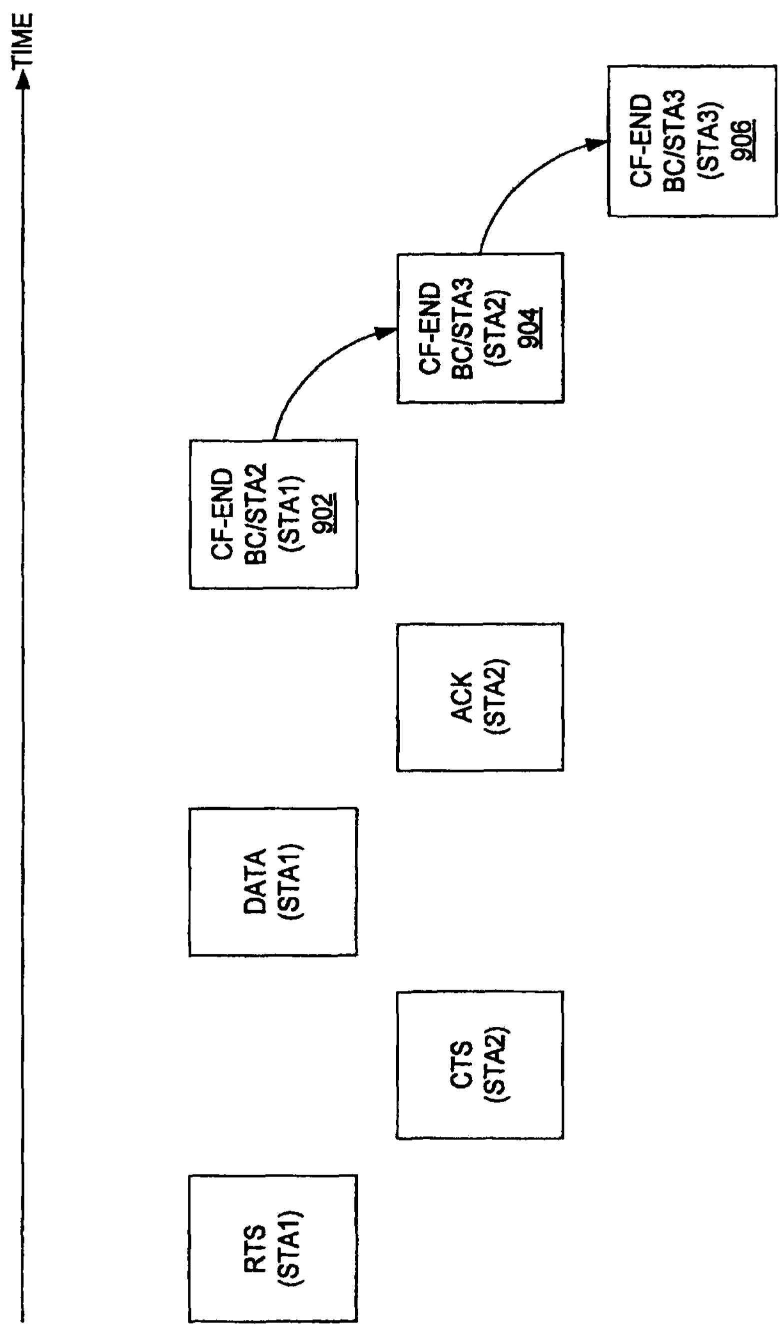
TIME
RTS (STA1)
CTS (STA2)
DATA (STA1)
ACK (STA2)
CF-END BC/STA2 (STA1) 902
CF-END BC/STA3 (STA2) 904
CF-END BC/STA3 (STA3) 906

FIG. 9

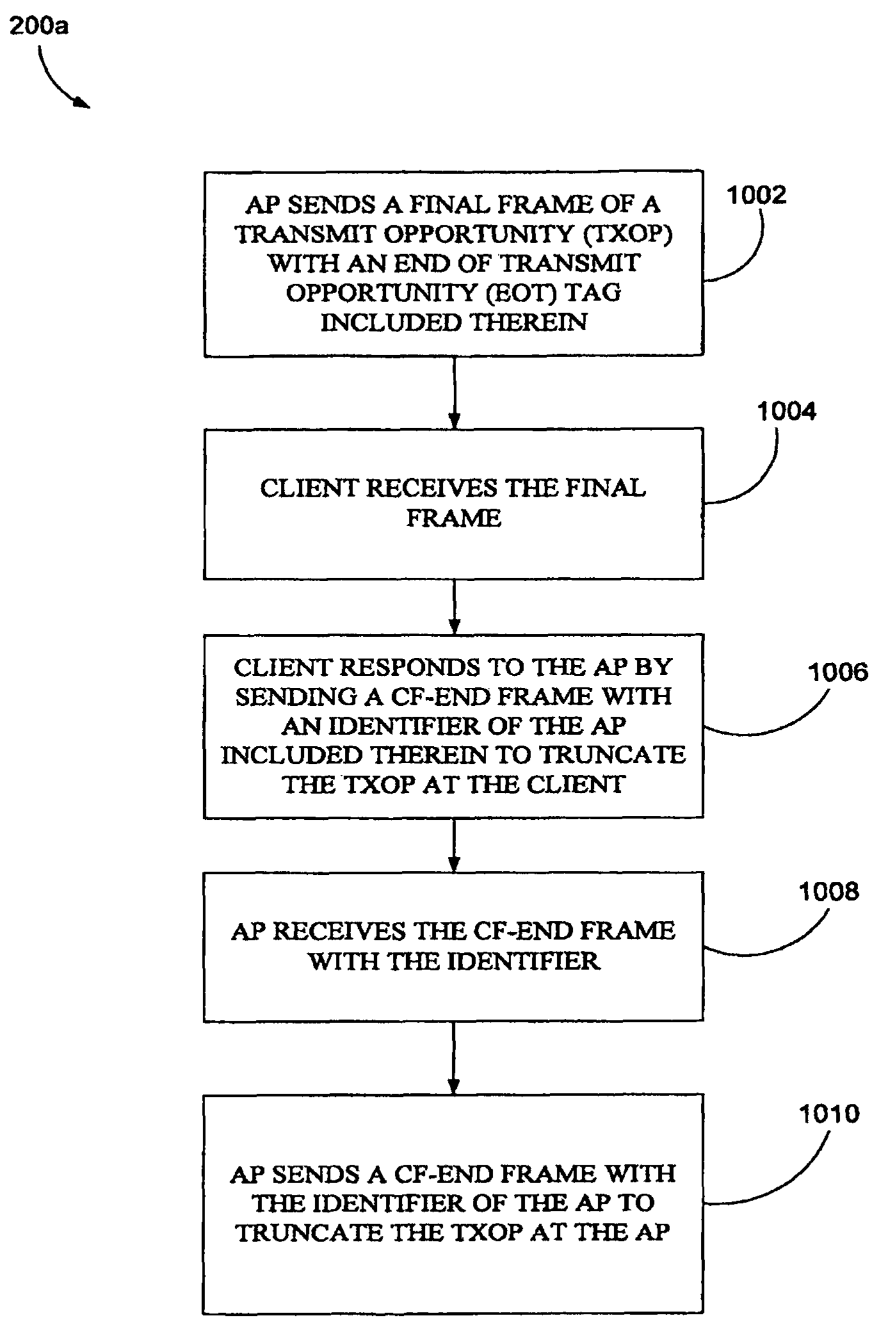
200a
AP SENDS A FINAL FRAME OF A TRANSMIT OPPORTUNITY (TXOP) WITH AN END OF TRANSMIT OPPORTUNITY (EOT) TAG INCLUDED THEREIN
1002
CLIENT RECEIVES THE FINAL FRAME
1004
CLIENT RESPONDS TO THE AP BY SENDING A CF-END FRAME WITH AN IDENTIFIER OF THE AP INCLUDED THEREIN TO TRUNCATE THE TXOP AT THE CLIENT
1006
AP RECEIVES THE CF-END FRAME WITH THE IDENTIFIER
1008
AP SENDS A CF-END FRAME WITH THE IDENTIFIER OF THE AP TO TRUNCATE THE TXOP AT THE AP
1010

FIG. 10

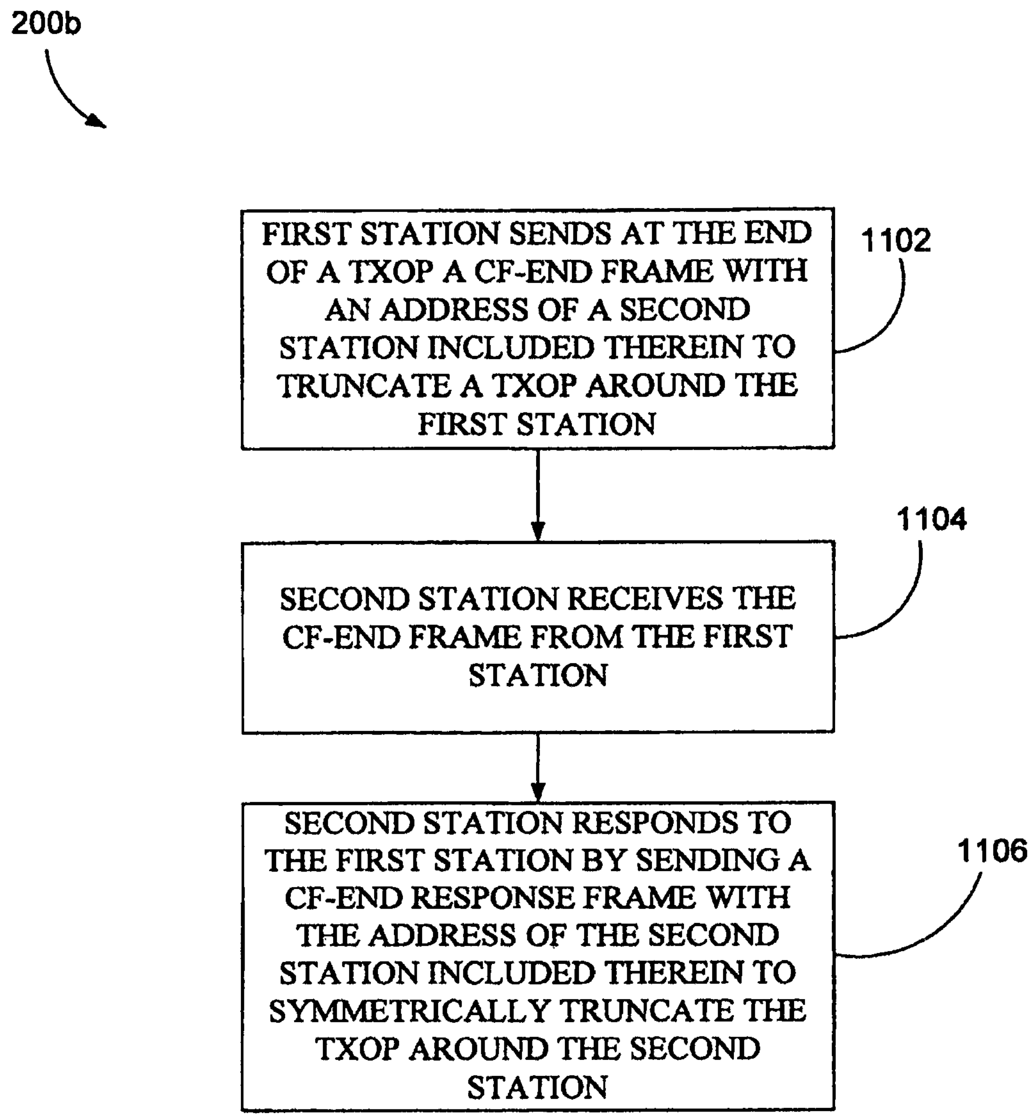
200b
FIRST STATION SENDS AT THE END OF A TXOP A CF-END FRAME WITH AN ADDRESS OF A SECOND STATION INCLUDED THEREIN TO TRUNCATE A TXOP AROUND THE FIRST STATION
1102
SECOND STATION RECEIVES THE CF-END FRAME FROM THE FIRST STATION
1104
SECOND STATION RESPONDS TO THE FIRST STATION BY SENDING A CF-END RESPONSE FRAME WITH THE ADDRESS OF THE SECOND STATION INCLUDED THEREIN TO SYMMETRICALLY TRUNCATE THE TXOP AROUND THE SECOND STATION
1106

FIG. 11

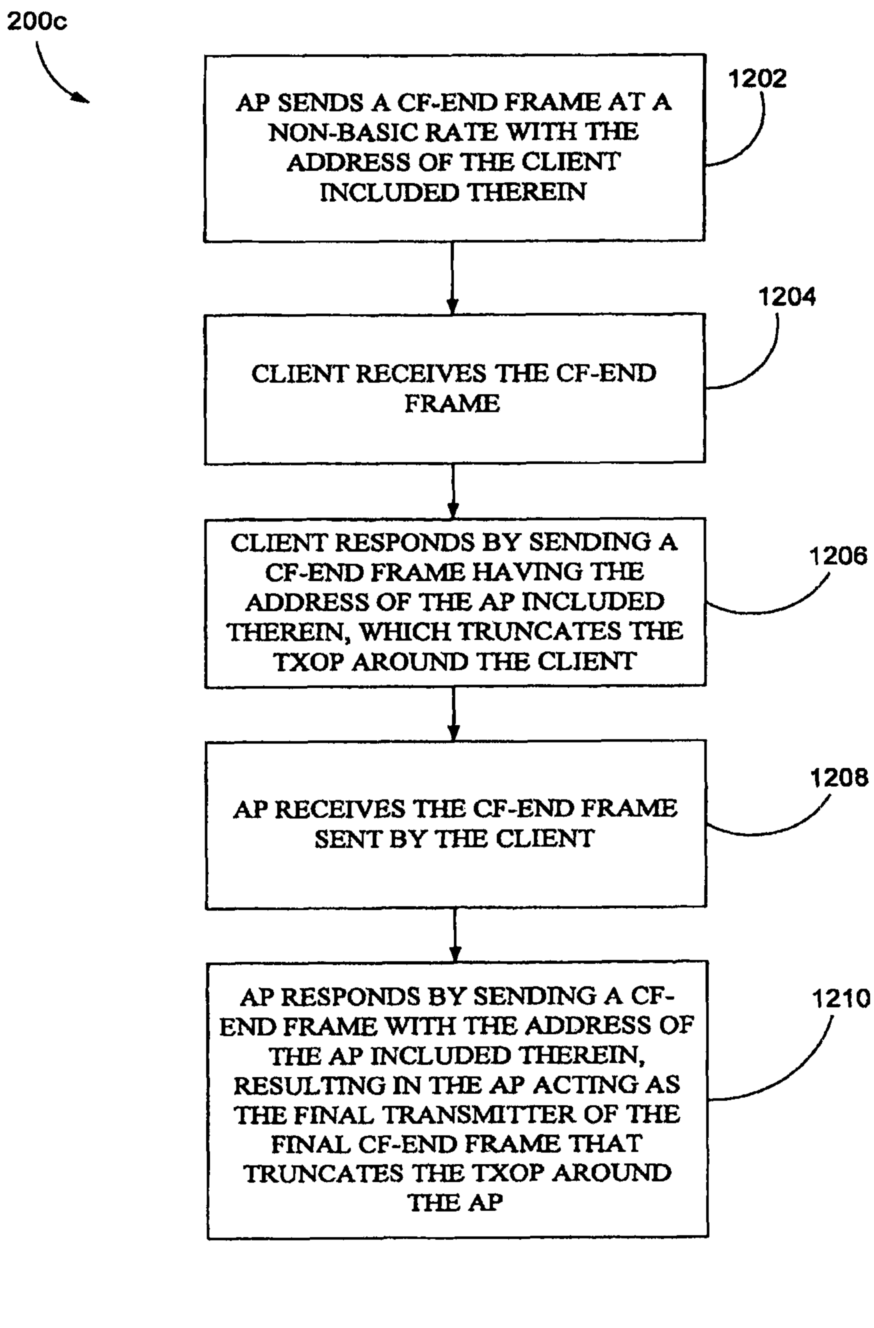
200c
AP SENDS A CF-END FRAME AT A NON-BASIC RATE WITH THE ADDRESS OF THE CLIENT INCLUDED THEREIN
1202
CLIENT RECEIVES THE CF-END FRAME
1204
CLIENT RESPONDS BY SENDING A CF-END FRAME HAVING THE ADDRESS OF THE AP INCLUDED THEREIN, WHICH TRUNCATES THE TXOP AROUND THE CLIENT
1206
AP RECEIVES THE CF-END FRAME SENT BY THE CLIENT
1208
AP RESPONDS BY SENDING A CF-END FRAME WITH THE ADDRESS OF THE AP INCLUDED THEREIN, RESULTING IN THE AP ACTING AS THE FINAL TRANSMITTER OF THE FINAL CF-END FRAME THAT TRUNCATES THE TXOP AROUND THE AP
1210

FIG. 12

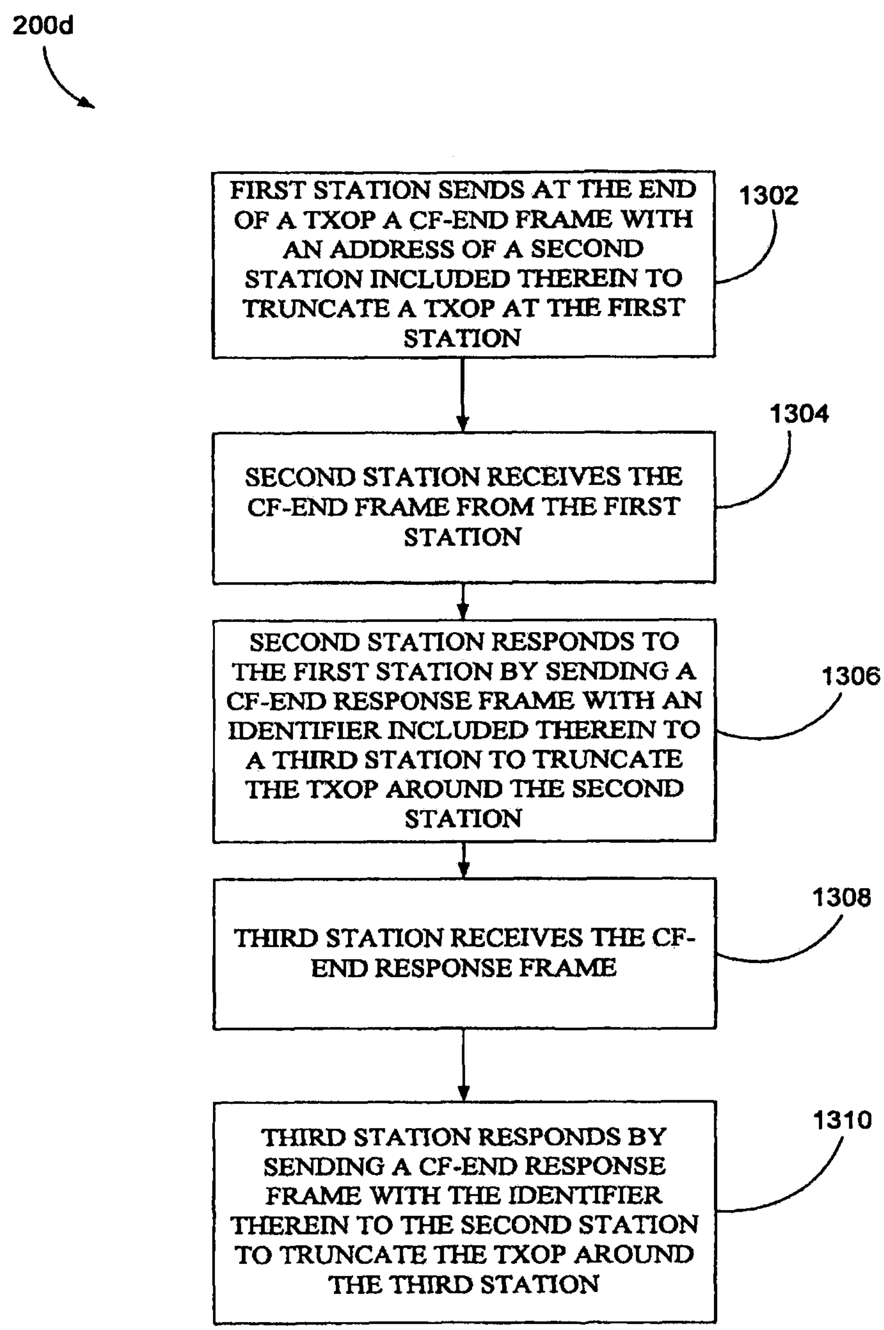
200d
FIRST STATION SENDS AT THE END OF A TXOP A CF-END FRAME WITH AN ADDRESS OF A SECOND STATION INCLUDED THEREIN TO TRUNCATE A TXOP AT THE FIRST STATION
1302
SECOND STATION RECEIVES THE CF-END FRAME FROM THE FIRST STATION
1304
SECOND STATION RESPONDS TO THE FIRST STATION BY SENDING A CF-END RESPONSE FRAME WITH AN IDENTIFIER INCLUDED THEREIN TO A THIRD STATION TO TRUNCATE THE TXOP AROUND THE SECOND STATION
1306
THIRD STATION RECEIVES THE CF-END RESPONSE FRAME
1308
THIRD STATION RESPONDS BY SENDING A CF-END RESPONSE FRAME WITH THE IDENTIFIER THEREIN TO THE SECOND STATION TO TRUNCATE THE TXOP AROUND THE THIRD STATION
1310

FIG. 13

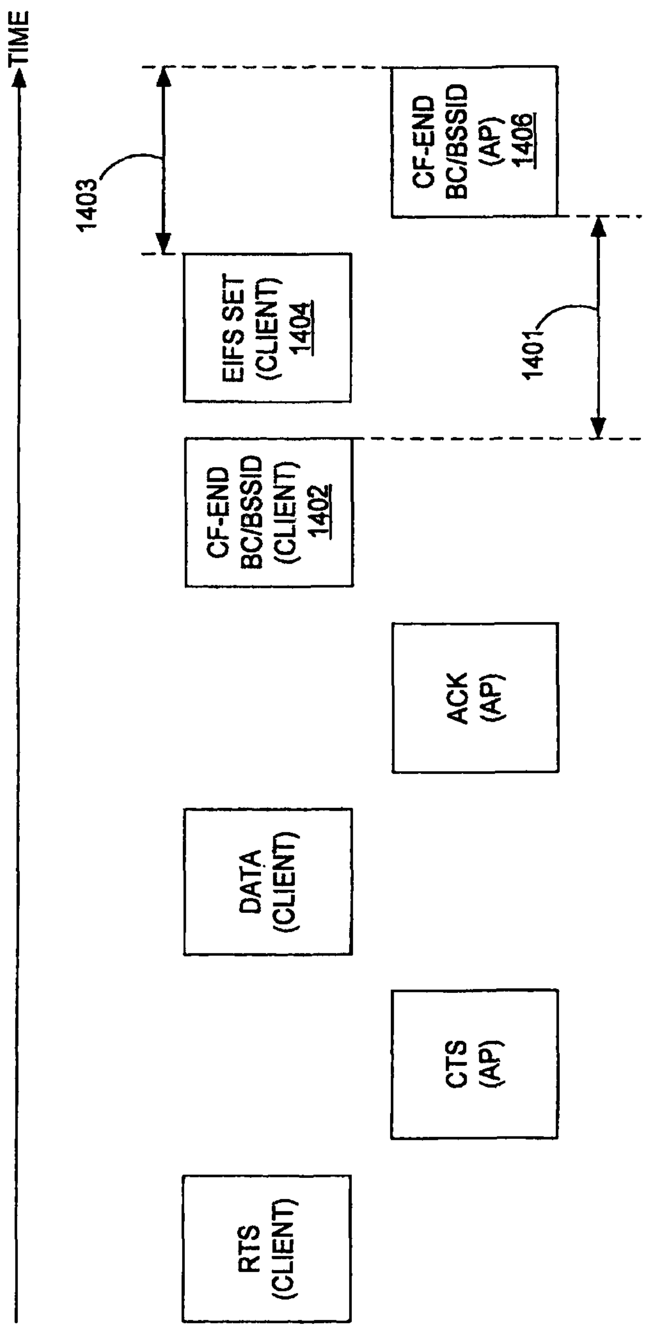
TIME
1403
CF-END
BC/BSSID
(AP)
1406
EIFS SET
(CLIENT)
1404
1401
CF-END
BC/BSSID
(CLIENT)
1402
ACK
(AP)
DATA
(CLIENT)
CTS
(AP)
RTS
(CLIENT)

FIG. 14

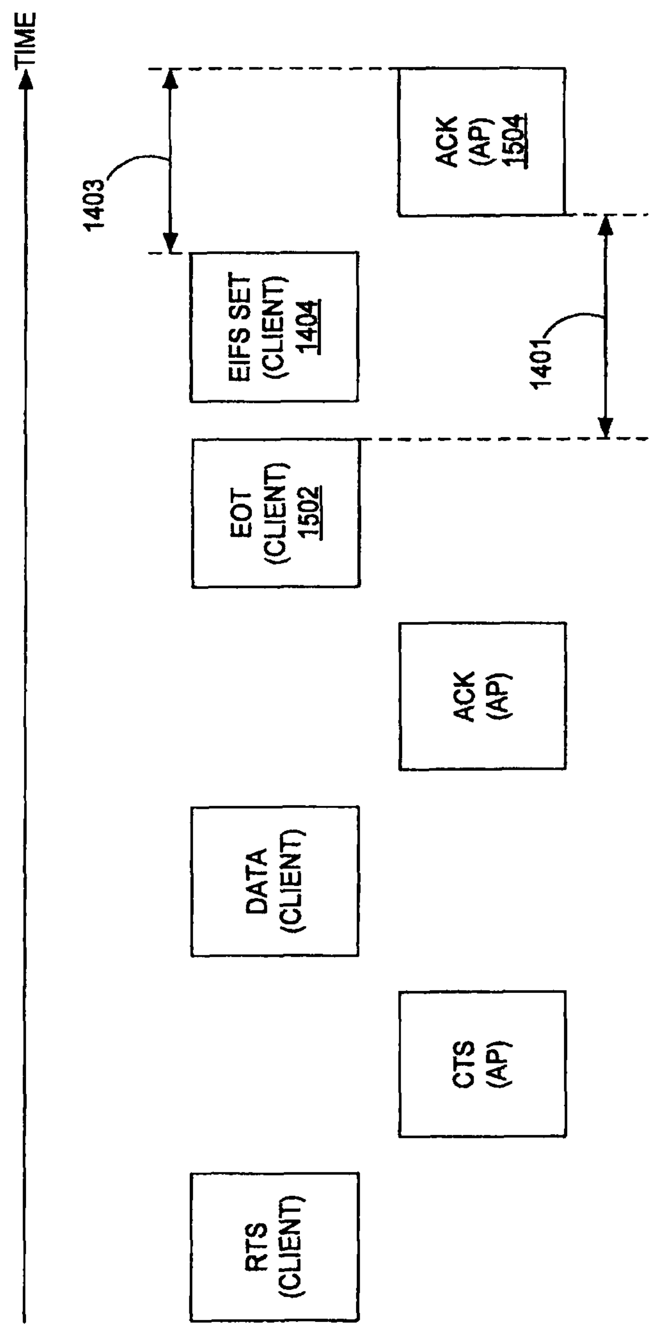
TIME
1403
ACK
(AP)
1504
EIFS SET
(CLIENT)
1404
1401
EOT
(CLIENT)
1502
ACK
(AP)
DATA
(CLIENT)
CTS
(AP)
RTS
(CLIENT)

FIG. 15

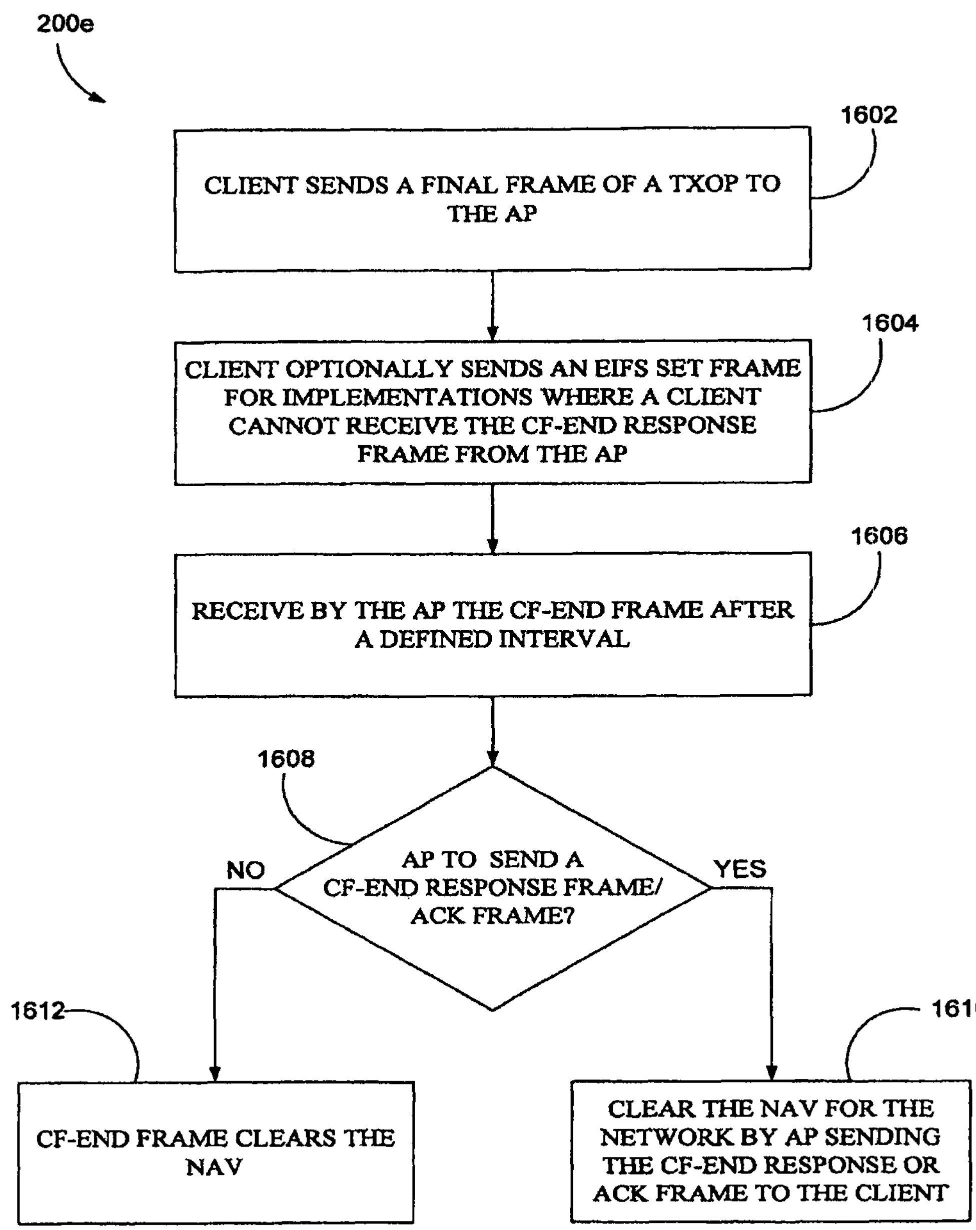
200e
1602
CLIENT SENDS A FINAL FRAME OF A TXOP TO THE AP
1604
CLIENT OPTIONALLY SENDS AN EIFS SET FRAME FOR IMPLEMENTATIONS WHERE A CLIENT CANNOT RECEIVE THE CF-END RESPONSE FRAME FROM THE AP
1606
RECEIVE BY THE AP THE CF-END FRAME AFTER A DEFINED INTERVAL
1608
AP TO SEND A CF-END RESPONSE FRAME/ ACK FRAME?
NO
YES
1612
CF-END FRAME CLEARS THE NAV
1610
CLEAR THE NAV FOR THE NETWORK BY AP SENDING THE CF-END RESPONSE OR ACK FRAME TO THE CLIENT

FIG. 16

SYMMETRIC TRANSMIT OPPORTUNITY (TXOP) TRUNCATION

CROSS-REFERENCE TO RELATED PATENT APPLICATIONS

This application is a Continuation of U.S. application Ser. No. 13/591,654, filed Aug. 22, 2012, which is a Continuation of U.S. application Ser. No. 13/251,772, filed Oct. 3, 2011, which is a Divisional of U.S. application Ser. No. 11/651,879, filed Jan. 10, 2007 (now U.S. Pat. No. 8,031,661), which claims the benefit of Provisional Application U.S. Application 60/757,827, filed Jan. 10, 2006. U.S. application Ser. No. 11/651,879 is also a Continuation-In-Part of U.S. application Ser. No. 11/557,516, filed Nov. 8, 2006, which claims the benefit of Provisional Application U.S. Application 60/735,024, filed Nov. 8, 2005, and Provisional Application U.S. Application 60/758,595, filed Jan. 11, 2006, all of which are incorporated herein by reference in their entirety.

BACKGROUND

1. Technical Field

The present disclosure is generally related to communication systems and methods and, more particularly, is related to collision avoidance systems and methods in wireless networks.

2. Related Art

Communication networks come in a variety of forms. Notable networks include wireline and wireless. Wireline networks include local area networks (LANs), DSL networks, and cable networks, among others. Wireless networks include cellular telephone networks, classic land mobile radio networks and satellite transmission networks, among others. These wireless networks are typically characterized as wide area networks. More recently, wireless local area networks and wireless home networks have been proposed, and standards, such as Bluetooth® and IEEE 802.11, have been introduced to govern the development of wireless equipment for such localized networks.

A wireless local area network (LAN) typically uses infrared (IR) or radio frequency (RF) communication channels to communicate between portable or mobile computer terminals and access points (APs) or base stations. These APs are, in turn, connected by a wired or wireless communications channel to a network infrastructure which connects groups of access points together to form the LAN, including, optionally, one or more host computer systems.

Wireless protocols such as Bluetooth® and IEEE 802.11 support the logical interconnections of such portable roaming terminals having a variety of types of communication capabilities to host computers. The logical interconnections are based upon an infrastructure in which at least some of the terminals are capable of communicating with at least two of the APs when located within a predetermined range, each terminal being normally associated, and in communication, with a single one of the access points. Based on the overall spatial layout, response time, and loading requirements of the network, different networking schemes and communication protocols have been designed so as to most efficiently regulate the communications.

IEEE Standard 802.11 ("802.11") is set out in "Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications" and is available from the IEEE Standards Department, Piscataway, N.J. The IEEE 802.11 standard permits either IR or RF communications at 1 Mbps, 2 Mbps and higher data rates, a medium access technique similar to carrier sense multiple access/collision avoidance (CSMA/CA), a power-save mode for battery-operated mobile stations, seamless roaming in a full cellular network, high throughput operation, diverse antenna systems designed to eliminate "dead spots," and an easy interface to existing network infrastructures. The IEEE Standard 802.11b extension supports data rates up to 11 Mbps.

The current 802.11 standard describes several methods to set a virtual carrier sense, referred to as a network allocation vector or NAV, most notably by request to send/clear to send (RTS/CTS) mechanisms. The sending of an RTS frame (herein, RTS frame also referred to as, simply, RTS) sets a NAV locally around the sender of the RTS, and the sending of a CTS frame (herein, CTS frame is also referred to as CTS) does the same locally around the sender of the CTS (e.g., the receiver of the RTS).

One problem that exists in current implementations under 802.11 involves what is referred to as a hidden node problem. For instance, in an infrastructure mode of a wireless LAN system, a first device may communicate frames to the AP and vice versa. Similarly, a second device may communicate frames to the AP, and vice versa. However, the second device may not detect transmissions from the first device (hence the phrase hidden node), for instance if the distance between the first and second device is too great. Because of the hidden node problem, various complications may arise in terms of collision avoidance and symmetry of response among devices, causing inequity in terms of opportunities for access to a shared medium of the communication system. For instance, in 802.11 compliant systems, the NAV can be reset by an access point (AP) through the transmission of what is commonly referred to as a CF-end frame. One exemplary frame format for a CF-end frame **10** is shown in FIG. **1**, and comprises two octets (exemplary quantity of octets shown beneath the frame **10**) corresponding to a frame control field **102**, two octets corresponding to duration field **104**, six octets corresponding to a receiver address (RA) field **106**, which usually contains the Broadcast Address (BC), six octets corresponding to a basic service set identifier (BSSID) field **108**, and four octets corresponding to a frame check sequence (FCS) field **110**. When the distance between a client station and an AP is large, one possible effect is that the area where the CF-end frame **10** is not received will not reset the NAV, resulting in inequitable access as described above.

SUMMARY

Embodiments of the present disclosure provide symmetric transmit opportunity (TXOP) truncation systems and methods in a wireless network. Briefly described, one embodiment of a method, among others, comprises receiving a frame that truncates a TXOP around a first station, and responsive to receiving the frame, sending a second frame that truncates the TXOP around a second station.

Another method embodiment, among others, comprises receiving a frame from an access point (AP) that includes an indicator of an end of a TXOP, responsive to receiving the indicator, sending a first frame that truncates the TXOP around a first station, receiving the first frame at the AP, and responsive to receiving the first frame at the AP, sending a second frame that truncates the TXOP around the AP.

Another method embodiment, among others, comprises sending at a first station a first frame, sending at the first station an extended interframe space (EIFS) set frame after the first frame, and sending at a second station a second frame having a completed transmission corresponding to time based

on an interval of EIFS less DIFS, the interval commencing from an end of the short frame.

One system embodiment, among others, comprises a processor configured with logic to receive a frame that truncates a TXOP around a first station and, responsive to receiving the frame, the processor further configured with the logic to send a second frame that truncates the TXOP around a second station.

Another system embodiment, among others, comprises means for receiving a frame that truncates a TXOP around a first station, and responsive to receiving the frame, means for sending a second frame that truncates the TXOP around a second station.

Other systems, methods, features, and advantages of the present disclosure will be or become apparent to one with skill in the art upon examination of the following drawings and detailed description. It is intended that all such additional systems, methods, features, and advantages be included within this description, be within the scope of the present disclosure, and be protected by the accompanying claims.

BRIEF DESCRIPTION OF THE DRAWINGS

Many aspects of the disclosure can be better understood with reference to the following drawings. The components in the drawings are not necessarily to scale, emphasis instead being placed upon clearly illustrating the principles of the present disclosure. Moreover, in the drawings, like reference numerals designate corresponding parts throughout the several views.

FIG. **1** is a block diagram that illustrates one exemplary frame format for a CF-end frame.

FIG. **2** is a block diagram of an exemplary environment in which various embodiments of a symmetric transmit opportunity (TXOP) truncation (STT) system may be implemented.

FIGS. **3**A-**3**B are block diagrams of that illustrate extended interframe space (EIFS) avoidance aspects to embodiments of the STT system as shown in FIG. **2**.

FIG. **4** is a block diagram that illustrates a mechanism employed by one embodiment of the STT system shown in FIG. **2** for an access point (AP) initiated TXOP where the AP signals the end of TXOP by setting an end of TXOP (EOT) indication on the final transmission to a client.

FIG. **5** is a block diagram that illustrates an alternative to the mechanism shown in FIG. **4** where the AP sends a CF-end with a client address, which is followed by a CF-end from the client with the same address of the client.

FIG. **6** is a block diagram that illustrates an alternative to the mechanism shown in FIG. **4** where the AP sends a CF-end with the client address in the location of a basic service set identifier (BSSID) field and the client responds with a CF-end with the BSSID and the AP responds with a final CF-end.

FIG. **7** is a block diagram that illustrates a mechanism employed by one embodiment of the STT system shown in FIG. **2** for a station-initiated TXOP that is terminated by a first station sending a CF-end with the address of the second station in the location of the BSSID field and the second station responding with a CF-end with the second station address in the BSSID field.

FIG. **8** is a block diagram that illustrates a mechanism employed by one embodiment of the STT system shown in FIG. **2** with a BSSID of a station which either transmitted the latest beacon in an independent basic service set (IBSS) or an AP in a Direct Link communication.

FIG. **9** is a block diagram that illustrates a mechanism employed by one embodiment of the STT system shown in FIG. **2** for a station-initiated TXOP that is terminated by a first station sending a CF-end to a second station, which responds with a CF-end to the third station, the latter which responds with a final CF-end.

FIG. **10** is a flow diagram that illustrates a method embodiment corresponding to the mechanism shown in FIG. **4**.

FIG. **11** is a flow diagram that illustrates a method embodiment corresponding to the mechanisms shown in FIGS. **5** and **7**.

FIG. **12** is a flow diagram that illustrates a method embodiment corresponding to the mechanisms shown in FIG. **6**.

FIG. **13** is a flow diagram that illustrates a method embodiment corresponding to the mechanisms shown in FIGS. **8**-**9**.

FIG. **14** is a block diagram that illustrates a NAV reset mechanism employed by an embodiment of the STT system shown in FIG. **2**.

FIG. **15** is a block diagram that illustrates an alternative to the NAV reset mechanism shown in FIG. **14** without using CF-end frames.

FIG. **16** provides a flow diagram that illustrates a method embodiment corresponding to the NAV reset mechanisms shown in FIGS. **14**-**15**.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Disclosed herein are various embodiments of symmetric transmit opportunity (TXOP) truncation (STT) systems and corresponding mechanisms or methods in a wireless network (herein, individually or collectively referred to also as an STT system or STT systems). The STT systems described herein comprise functionality to truncate a TXOP in a symmetric manner in a plurality of devices. That is, in various STT systems and methods described herein, both access points (APs) and client stations (herein, clients) are also allowed to truncate their TXOPs by transmitting a CF-end frame. This truncation is referred to as a TXOP truncation, where a NAV is first set for some maximum duration of time (e.g., the TXOP limit) and then reset when no more traffic (e.g., of frames) is left and there is some NAV time that still remains. In general, a TXOP comprises a signal exchange which may begin with the transmission of a short frame such as an RTS or CTS and ends with the last frame sent or received by the sender of the short frame (e.g., sender of the RTS or CTS). The truncation at both clients and APs resolve the various problems resulting from a reset that is not symmetrical, such as in conventional systems where the reset comes from a single device (though set by both devices through the RTS/CTS mechanisms). Various embodiments of the STT systems provide one or more mechanisms for the symmetrical truncation of TXOPs.

Thus, although described mostly in the context of a wireless local area network (WLAN) environment having a basic service set (BSS) configured in an infrastructure mode, the various embodiments of the STT systems described herein may similarly be applied to other systems and environments, such as ad hoc systems (e.g., independent BSS (IBSS) systems) or DLC systems, as well as other communication system environments. Additionally, although IEEE 802.11 is prominently used herein as an example of a standard used in the disclosed exemplary wireless networks, the various systems and methods described herein may apply to virtually any wireless network. Further, some embodiments of the STT systems may include some or all of the functionality of collision avoidance systems (CA systems) described in the copending application having Ser. No. 11/557,516 and incorporated herein by reference in its entirety.

FIG. **2** shows an exemplary wireless LAN (WLAN) environment **100** in which various embodiments of a symmetric transmit opportunity (TXOP) truncation (STT) system **200** may be implemented. In general, the STT system **200** is configured as a basic service set (BSS), which comprises a plurality of stations or nodes, such as stations **202**, **204**, and **206**. Each of the stations **202**, **204**, and **206** may be embodied as one of many wireless communication devices, including computers (desktop, portable, laptop, etc.), consumer electronic devices (e.g., multi-media players), compatible telecommunication devices, personal digital assistants (PDAs), or any other type of network devices such as printers, fax machines, scanners, hubs, switches, routers, set-top boxes, televisions with communication capability, etc.

The STT system **200** shown in FIG. **2** comprises, in one embodiment, an access point (AP) station **202** (herein, also referred to, simply, as an AP) and one or more client stations **204**, **206** (herein, also referred to individually or collectively as client(s)). The STT system **200** is configured in what may be referred to as an infrastructure mode, whereby clients **204** and **206** communicate frames directly with the AP **202** and not with each other. However, the various embodiments of STT systems **200** are not limited to such arrangements, and in some embodiments, may be arranged in ad hoc or direct link communication configurations. Included within each of the AP **202** and clients **204**, **206** is control logic **300**. The control logic **300** implements MAC layer and PHY layer services. The MAC layer services provide the capability for a given station to exchange MAC frames. The MAC layer services provide management, control, or data frames for transmission between stations **202**, **204**, and **206**. The 802.11 MAC layer services make use of at least three frame types (data, management, control), and within each type, various subtypes. For instance, request-to-send (RTS) frames, clear-to-send (CTS) frames, and CF-end frames are examples of control subtypes (e.g., control/CF-end refers to a control-type frame of the subtype, CF-end). After a station forms the applicable MAC frames, the frame bits are passed to the PHY layer for transmission. One skilled in the art can understand in the context of this disclosure that the control logic **300** can be configured using a plurality of modules (e.g., hardware and/or software), each with distinct functionality, or as a single module comprising a plurality of functionality.

The control logic **300** can be implemented in hardware, software, or a combination thereof. When implemented in whole or in part by software, control logic **300** is implemented in software stored in a memory that is executed by a suitable instruction execution system. When implemented in whole or in part by hardware, the control logic **300** can be implemented with any or a combination of the following technologies, which are all well known in the art: a discrete logic circuit(s) having logic gates for implementing logic functions upon data signals, an application specific integrated circuit (ASIC) having appropriate combinational logic gates, a programmable gate array(s) (PGA), a field programmable gate array (FPGA), etc. In one embodiment, the control logic **300** may include a PHY layer processor, MAC layer processor, or a combination of both (in the same or separate units), including, but not limited to, a digital signal processor (DSP), a microprocessor unit (MCU), a general purpose processor, and an application specific integrated circuit (ASIC), among others.

The AP **202** is typically connected to a wired network (e.g., Ethernet), not shown. In general, the clients, such as client **204**, connect to the AP **202** through a scanning process. The scanning process can either be performed passively by listening for a beacon transmitted by one or more APs **202**, or actively by sending out probes to one or more APs **202** and choosing an AP that provides the best connection (e.g., in terms of signal strength and/or bit error ratio (BER)). After an AP is chosen, such as AP **202**, an authentication process occurs between the client **204** and the AP **202**, and then association between the client **204** and the AP **202** may begin.

Association involves the communication between the clients **204**, **206** and the AP **202** via a shared wireless medium **208**. In one implementation, the client **206** may represent a hidden node to client **204**, and vice versa. Various mechanisms or methods for signal exchanges are illustrated in FIGS. **3**A-**16** to highlight various features of embodiments of the STT system **200**. Although described below in the context of the AP **202** or client **204** (or similarly client **206**) sending or receiving various transmissions, it can be understood in the context of this disclosure that the effectuating of the various functionality of the STT system **200** is through the control logic **300** of each station (node). Further, the various interframe spaces (e.g., extended interframe space (EIFS), short interframe space (SIFS), etc.) described in 802.11 and understood by those having ordinary skill in the art are omitted from the various figures (and corresponding description) except where helpful to the understanding of the various embodiments.

Before describing the various symmetrical TXOP truncation mechanisms of embodiments of the STT system **200**, an embodiment of an STT system **200** that performs an AP-initiated TXOP is described in association with FIGS. **3**A-**3**B. That is, FIGS. **3**A-**3**B show one mechanism used by an embodiment of the STT system **200** to set a NAV and/or avoid EIFS for an AP-initiated TXOP. Referring to FIG. **3**A, the AP **202** sets a NAV prior to a TXOP **302** by starting the TXOP **302** with a short frame **304** (e.g., short to reduce the probability of error) at a low basic rate. Note that blocks **302** and **304** collectively comprise a TXOP. The short frame **304** contains a duration value (e.g., the NAV setting) equal to the expected length of the TXOP **302**. Referring to FIG. **3**B, the AP **202** avoids any EIFS at the end of the TXOP **302** by sending a short frame **306** (typically containing a duration value of zero) at a low basic rate as the final frame of the TXOP **302**. Note that blocks **302** and **306** collectively comprise a TXOP. In each case, the rate is selected such that frames from the AP **202** reach all nodes in the network (e.g., BSS).

The description that follows and the associated figures (FIGS. **4**-**9**) disclose various mechanisms employed (implemented) by certain embodiments of the STT system **200** that provide for symmetrical TXOP truncation using CF-end frames (herein, each of these frames also simply referred to as CF-end). In particular, various mechanisms of communication between devices of one or more STT system embodiments are illustrated in FIGS. **4**-**9** and explained in the corresponding text. For instance, shown in FIG. **4** are blocks representing respective frames that are passed between the client **204** and the AP **202** to provide for symmetrical TXOP truncation. As noted from FIGS. **4**-**9**, the AP-sourced frames are represented with blocks in the top row (indicated in parenthesis, with "AP"), and the client-sourced frames are represented with blocks in the second row (as indicated in the parenthesis as "client"). The sequence of frame transmission advances in time from left to right, as represented by the arrow time line **401**. For instance, for the exemplary communication shown in FIG. **4**, an RTS frame sent by the AP **202** begins the sequence, and a CF-end sent by the AP **202** ends the sequence. Note that the first address (e.g., BC) is the receiver address, which should be the broadcast address so that the CF-end is received by all stations. The second address (e.g., BSSID) is usually the transmitter address, but in one or more embodiments described herein, comprises the unicast destination address.

In particular, the AP **202** (not shown, but implied as denoted by the "AP" in parenthesis) sends an RTS frame (or RTS) **402**, and the client **204** (not shown, but implied as denoted by the "client" in parenthesis) responds by sending a CTS frame (or CTS) **404**. The sending of the RTS **402** and CTS **404** results in the setting of a NAV around (e.g., close enough to decode frame transmissions all or at least most of the time) the respective devices. The AP **202** sends one or more data frames **406**, each of which are acknowledged by the client **204** with an acknowledgement (ACK) frame **408**. The final data frame **406** from the AP **202** to the client **204** is "tagged" with an end of TXOP (EOT) indication. This EOT indication comprises a signal or flag to the client **204** to respond with a CF-end frame **410** after a SIFS interval. In some implementations, the CF-end frame **410** may be preceded by a mandatory response frame, such as the ACK frame **408** (or a block acknowledgement (BA) frame, the latter not shown). A basic service set identifier (BSSID) field of the CF-end frame **410** carries a BSSID (e.g., MAC address) of the AP **202**. The AP **202** recognizes its BSSID in the received CF-end frame **410** and responds to this CF-end frame **410** with a CF-end frame **412**. By the AP **202** sending the CF-end frame **412**, the TXOP is actively truncated by both devices **202** and **204**.

FIG. **5** illustrates an alternative to the mechanism shown in FIG. **4**. That is, the final frame in the TXOP sent by the AP **202** is a CF-end frame **502** comprising the address (e.g., MAC address) of the client **204** inside the BSSID field. The client **204** recognizes its address in the CF-end frame **502** and responds after a SIFS interval with a CF-end frame **504**. The CF-end frame **504** also comprises the client address inside the location of the BSSID field. This mechanism illustrated in FIG. **5** is referred to as a "CF-end to self"

FIG. **6** illustrates an alternative to the mechanism shown in FIG. **4**. The AP **202** sends a CF-end frame **602** with the client MAC address inside the BSSID field. The client responds with a CF-end frame **604** having the BSSID of the AP **202**, to which the AP **202** responds with a CF-end frame **606** with the BSSID of the AP **202**. Hence, the AP **202** acts as the final transmitter of the final CF-end frame, which may be desirable in relation to the EIFS inside a BSS since all associated clients receive the final CF-end frame (e.g., CF-end frame **606**) from the AP **202**. The first CF-end frame **602** uses a non-basic rate, and thereby functions similarly to the EOT frame indication (of final frame **406**) shown in and described in association with FIG. **4**. By using a non-basic rate for the first CF-end frame **602**, NAV truncation functionality is absent. That is, a CF-end frame is effective for NAV truncation when sent at a basic rate that all clients inside a defined BSS can receive and decode.

Having described various exemplary mechanisms used by the STT system **200** for providing symmetrical truncation, the following description (and associated figures) generalizes some of the above-noted mechanisms for communications between stations (e.g., either AP **202** or clients **204**, **206**) and provides additional mechanisms. That is, FIGS. **7-9** provide a generalized illustration of the above-described mechanisms, in addition to describing additional mechanisms, by showing an exchange of frames between two stations, station **1** (STA**1**) (shown in a top row of FIGS. **7-9**) and station **2** (STA**2**) (shown in a second row of FIGS. **7-9**). In some embodiments, there may be an exchange of frames with a third station such as an AP or other device (shown in a third row at the bottom of FIGS. **8-9**). The explanation of the various mechanisms shown in FIGS. **7-9** is directed to the exchange of frames that commence after the exchange of CTS/RTS frames and data and ACK frames, the latter of which have already been described above in association with FIGS. **4-6**.

FIG. **7** illustrates a general principle of certain embodiments of the STT system **200** that any station that receives a CF-end frame **702** with its corresponding MAC address inside the location of the BSSID field responds to the CF-end frame **702** with a CF-end frame **704**. The address used inside the CF-end frame **702** depends on the specific implementation. In general, if a CF-end frame **704** is required (a determination to be made by a client or an AP), the address of the transmitter of the next CF-end frame **704** is included inside the location of the BSSID field of CF-end frame **702**. If no CF-end frame **704** (also referred to herein as a CF-end response frame) is required and the CF-end frame **702** is the final frame of the sequence, the station's (e.g., STA**2**) own address is included in the BSSID field, or the broadcast address (BC), or any other address which is not immediately associated with another station address. Such a scheme is applicable in an IBSS or Direct Link environment as well. In general, a client in infrastructure mode would typically include the BSSID of the AP, so that the AP generates a CF-end response. Further, a client in IBSS mode may include the MAC address of the peer node to which it is communicating during the TXOP. An AP may or may not include an address other than a BSSID of the AP.

Consider the case where STA**1** comprises a client station **204**, and STA**2** comprises an AP station (or simply, AP) **202**. The mechanism shown in FIG. **7** enables the AP **202** to respond to a CF-end **702**, which contains a matching BSSID (e.g., MAC address) with another CF-end **704** after SIFS (which in some implementations, may be a PIFS interval). The CF-end **702** transmitted by the client station **204** comprises the final frame in the TXOP of client station **204**, and in one embodiment, is an unacknowledged frame (hence, it is safe to transmit a CF-end **704** after SIFS). The BSSID makes the CF-end **702** specific to one AP, avoiding collisions between multiple APs transmitting a CF-end **704**. The CF-end **704** clears the NAV around the AP **202**, which covers the entire BSS. Note that some implementations may not require the CF-end **704**. For instance, when the distance between the AP **202** and the client station **204** is small, a single CF-end from either the AP **202** or the client station **204** roughly resets the EIFS in the same coverage area, because the coverage areas for both devices largely overlap. The determination by the AP **202** to send a CF-end response (CF-end **704**) can be based on the estimated distance of associated client stations **204**, **206**, and possibly in combination with the estimated distance of the transmitter of the CF-end. Such a determination can, for instance, be based on received signal strengths, or the PHY rates or modulation code schemes (MCSs) used to communicate with the client stations **204**, **206**. Other mechanisms may be used in the determination.

Continuing the case where STA**1** is a client **204** and STA**2** is an AP **202**, the client **204** may send a CF-end **702** with a duration value (which sets a NAV) corresponding to a defined time after the expected CF-end **704** to be sent by the AP **202**. The AP **202** sends a CF-end **704** (CF-end response) with a duration of zero, which causes receivers of each CF-end to resume backoff at exactly, or substantially exactly, the same time (and hence, in one embodiment, superceding existing rules that allow an EIFS to follow a CF-end). The client **204** may also send a CF-end **702** with a physical layer convergence protocol (PLCP) duration (which is signaled inside a SIG field or L-SIG field of the frame) equal to the CF-end itself plus SIFS plus the expected CF-end response duration from the AP **202**. The AP **202**, in one embodiment, is allowed to ignore this physical duration and respond with a CF-end **704** a SIFS interval after the end of the actual transmission of the CF-end **702**, as can be determined from the indicated rate and size of the CF-end **702** (e.g., 20 octets without an HT control field, 24 octets with an HT control field). The CF-end **704**, in one embodiment, comprises a regular PLCP duration. The mechanisms described below in association with FIGS. **14** and **15** address situations where there is a difference in when the NAV gets reset and backoff resumes.

In some embodiments, a third CF-end frame may be added to the frame sequence illustrated in FIG. **7** when the second station includes the BSSID. Such a situation is illustrated in FIG. **8**, which includes the addition of an AP (implicitly represented by the bottom or third row frame **802**). The TXOP is initiated by STA**1** sending a CF-end frame **802** to STA**2**, which responds with a CF-end frame **804** to the AP. As shown, the AP responds with a final CF-end frame **806** with the BSSID inside the BSSID field of CF-end frame **806**.

In an IBSS implementation, the BSSID may be recognized by the station that transmitted the final IBSS beacon, as illustrated in FIG. **9**. As shown, STA**1** sends a CF-end frame **902** addressed at STA**2**. STA**2** responds with a CF-end frame **904** addressed at the BSSID of STA**2**. STA**3** responds with a CF-end frame **906**. The BSSID can be the address of the station (e.g., STA**3**) that transmitted the latest beacon in an IBSS, or it can be the address of the AP in case the communication between STA**1** and STA**2** comprises a Direct Link communication.

In some embodiments, the receiver address (RA) of a CF-end frame is equal to the broadcast address, which ensures that all stations within range receive the CF-end frame and process the same. The location of the BSSID can be used to indicate the destination of the CF-end. Further, in some embodiments, the recognition of the CF-end type/subtype is enough for a receiver to truncate the NAV. In such implementations, the RA of the CF-end frame can be used to store the CF-end responder address, while the BSSID field can be used to store the BSSID.

Having described various embodiments of the STT system **200** above, it can be appreciated in the context of this disclosure that one method embodiment, referred to as STT method **200***a* corresponding to the mechanism shown in FIG. **4** and shown in the flow diagram of FIG. **10**, comprises sending by an AP a final data frame of a transmit opportunity (TXOP) with an end of transmit opportunity (EOT) indicator included therein (**1002**), receiving by a client the final data frame (**1004**), the client responding by sending a CF-end frame, with an identifier (e.g., MAC address, etc.) of the AP included therein, to the AP to truncate the TXOP around the client (**1006**), the AP receiving the CF-end frame with the identifier (**1008**), and the AP sending a CF-end frame with the same identifier to the client to truncate the TXOP around the AP (**1010**).

It can be appreciated that portions of the method embodiment **200***a* are implemented at each device, and hence such portions can be described from the perspective of the individual devices of the system **200**. For instance, one method embodiment corresponding to method **200***a*, viewed from the perspective of an AP, comprises sending (by an AP) a final data frame of a transmit opportunity (TXOP) with an end of transmit opportunity (EOT) indicator included therein, and responsive to receiving a CF-end frame with an identifier of the AP included therein to truncate the TXOP around the client, sending a CF-end frame with the same identifier to the client to truncate the TXOP around the AP.

Another method embodiment corresponding to method **200***a*, from the perspective of a client, comprises receiving (by a client) a final frame of a transmit opportunity (TXOP) from an AP, the final data frame having an end of transmit opportunity (EOT) indicator included therein, responding to the final frame by sending a CF-end frame, with an identifier of the AP included therein, to the AP to truncate the TXOP around the client and to prompt the AP to send a CF-end frame to truncate the TXOP around the AP.

Another embodiment, referred to as STT method **200***b* corresponding to the mechanisms illustrated in FIGS. **5** and **7** and shown in the flow diagram of FIG. **11**, comprises sending, by a first station (e.g., an AP), at the end of a TXOP a CF-end frame with an address of a second station (e.g., a client) included therein to truncate a TXOP around the first station (**1102**), receiving by the second station the CF-end frame from the first station (**1104**), the second station responding to the first station by sending a CF-end frame with the address of the second station included therein to truncate the TXOP around the second station (**1106**).

It can be appreciated that portions of the method embodiment **200***b* are implemented at each device (e.g., stations, whether configured as an AP or client), and hence such portions can be described from the perspective of the individual devices of the system **200**. For instance, one method embodiment corresponding to method **200***b* implemented at a first station (e.g., AP) comprises receiving a final frame of a TXOP from a second station (e.g., client) at the first station, and responsive to receiving the final frame of the TXOP, sending, at the end of the TXOP, a CF-end frame with an address of the second station included therein to truncate a TXOP around the first station and to prompt the second station to send a CF-end frame to truncate the TXOP around the second station.

Additionally, one method embodiment corresponding to method **200***b* implemented at a second station (e.g., client) comprises receiving (at the second station) a CF-end frame with an address of the second station included therein, the CF-end used to truncate a TXOP around a first station (e.g., AP), and responding to the first station by sending a CF-end frame with the address of the second station included therein to truncate the TXOP around the second station.

Another method embodiment, referred to as STT method **200***c* corresponding to the mechanism illustrated in FIG. **6** and shown in the flow diagram of FIG. **12**, comprises an AP sending a CF-end frame at a non-basic rate (and hence acting as an EOT indicator) with the address of the client included therein (**1202**), the client receiving the CF-end frame (**1204**), the client responding by sending a CF-end frame having the address of the AP included therein, which truncates the TXOP around the client (**1206**), the AP receiving the CF-end frame sent by the client (**1208**), and the AP responding by sending a CF-end frame with the address of the AP included therein, resulting in the AP acting as the final transmitter of the final CF-end frame that truncates the TXOP around the AP (**1210**).

It can be appreciated that portions of the method embodiment **200***c* are implemented at each device, and hence method embodiments can be described from the perspective of the AP and client. One method embodiment corresponding to method **200***c* implemented at an AP comprises an AP sending a CF-end frame at a non-basic rate (and hence acting as an EOT indicator) with the address of the client included therein, and responsive to receiving a client-TXOP truncating CF-end frame having the address of the AP included therein, responding by sending a CF-end frame with the address of the AP included therein, which truncates the TXOP around the AP.

Additionally, one method embodiment corresponding to method **200***c* implemented at a client comprises receiving by a client a CF-end frame possibly at a non-basic rate (and hence acting as an EOT indicator) with the address of the client included therein, and responding by sending a CF-end frame having the address of the sending AP included therein, which truncates the TXOP around the client and prompts the AP to send a final CF-end frame that truncates the TXOP around the AP.

Another method embodiment, referred to as STT method **200***d* corresponding to the mechanisms illustrated in FIGS. **8-9** and shown in the flow diagram of FIG. **13**, comprises sending, by a first station, at the end of a TXOP a CF-end frame with an address of a second station included therein to truncate a TXOP around the first station (**1302**), receiving by the second station the CF-end frame from the first station (**1304**), the second station responding to the first station by sending a CF-end frame with an identifier included therein to a third station to truncate the TXOP around the second station (**1306**), the third station receiving the CF-end response frame (**1308**), the third station responding by sending a CF-end response frame with the identifier therein to the second station to truncate the TXOP around the third station (**1310**).

It can be appreciated by one having ordinary skill in the art, in the context of this disclosure, that each device participating in the methodology illustrated in FIG. **13** performs portions of the described method **200***d* that can be described similarly to the manner such perspective-based methods have been described previously in FIGS. **10-12**, and thus omitted here for brevity.

FIG. **14** illustrates various mechanisms for client-initiated TXOPs for embodiments of the STT system **200**, and in particular, mechanisms that focus on issues of NAV reset and backoff resumption involving CF-end frames or frames acting in particular circumstances with similar functionality to CF-end frames. The description that follows is based in part on the previous discussion corresponding to FIG. **7** for the case where STA**1** is a client and STA**2** is an AP. To solve the difference in when a NAV gets reset and the backoff resumes, the client may transmit a short frame (EIFS set frame) **1404** with a defined frame check sequence (FCS) field **110** (FIG. **1**), which is not the correct FCS (e.g., if the FCS is correct, then stations start an EIFS rather than a DCF Interframe Space/Arbitration Interframe Space or DIFS/AIFS), at a SIFS time after the CF-end frame **1402**. The transmission of this short frame **1404** in the manner as described above causes receivers (e.g., clients **204**, **206**) to start an EIFS. The AP **202** delays (e.g., by SIFS+EIFS set frame+EIFS-DIFS-CF-end frame, represented by duration interval **1401**) the sending of the CF-end frame **1406** so that the transmission of frame **1406** finishes exactly (or substantially so) when the EIFS-DIFS finishes (the EIFS-DIFS represented by the duration interval denoted by **1403**), so that either client (e.g., **204**, **206**) starts DIFS (or more general, AIFS) at the same time. The DIFS refers to a first fixed part of the DCF backoff (DIFS), and the AIFS refers to the EDCA backoff (AIFS). As is known, EDCA is similar to DCF but with QoS differentiation (802.11e). The AP **202** does not start an EIFS and ignores the intermediate EIFS set frame **1404**. Thus, the EIFS set frame **1404** causes AIFS to start for clients **204**, **206** that cannot receive the CF-end **1406** from the AP **202**. The CF-end frame **1406** from the AP **102** is transmitted during this time, such that all nodes start DIFS (or AIFS) at the same time. Note that in some embodiments, the EIFS set frame **1404** can be a zero length frame (e.g., a preamble without a MAC payload).

FIG. **15** is a block diagram that illustrates the principles of the mechanism shown in FIG. **14**, without the use of CF-end frames. In other words, the CF-end frame **1402** of FIG. **14** is replaced with an EOT frame **1502**, and the CF-end frame **1406** of FIG. **14** is replaced with an ACK frame **1504**. The mechanism illustrated in FIG. **15** can be used to resume the backoff for all nodes within the range of either the client **204** or the AP **202** or both in the network at the same time (e.g., without part of the nodes having to wait for an EIFS to finish). The EOT frame **1502** is sent to the AP **202**, followed after an SIFS interval by the EIFS set frame **1404**. The AP **202**, through a similar delay **1401** and similar manner to the mechanism described in association with FIG. **14**, responds to the EOT frame **1502** (and ignores the EIFS set frame **1404**) with the ACK frame **1504**. The ACK frame **1504** ends at the same time as the interval **1403** after the end of the EIFS set frame **1404**. Note that in some embodiments, both the AP and the client can start an EIFS set frame at the same, or substantially same, time.

Having described the various mechanisms shown in FIGS. **14-15**, one method embodiment of the STT system **200** encompassing these mechanisms, the method referred to as **200***e* and shown in FIG. **16**, comprises the client **204** sending a final data frame of a TXOP to the AP **202** (**1602**), the final frame having the form of a CF-end frame specific to a given AP or an EOT frame, sending an EIFS set frame (**1604**), receiving by the AP **202** the CF-end frame after a defined interval (the defined interval being a SIFS, a PIFS, or duration **1401** described in association with FIG. **14**) (**1606**), and responsive to deciding to send the CF-end response frame or ACK frame, clearing the NAV for the network (e.g., BSS) by sending the CF-end response frame or ACK frame to the client **204** (**1610**). Responsive to deciding not to send the CF-end response frame, the CF-end frame acts to clear the NAV (**1612**), as described above.

It can be appreciated by one having ordinary skill in the art, in the context of this disclosure, that each device participating in the methodology illustrated in FIG. **16** performs portions of the described method **200***e* that can be described similarly to the manner such perspective-based methods have been described previously in FIGS. **10-12**, and thus omitted here for brevity.

Any process descriptions or blocks in flow charts should be understood as representing modules, segments, or portions of code which include one or more executable instructions for implementing specific logical functions or steps in the process, and alternate implementations are included within the scope of the present disclosure in which functions may be executed out of order from that shown or discussed, including substantially concurrently or in reverse order, depending on the functionality involved, as should be understood by those reasonably skilled in the art of the present disclosure.

It should be emphasized that the above-described embodiments of the present disclosure are merely possible examples of implementations, merely set forth for a clear understanding of the principles of the disclosure. Many variations and modifications may be made to the above-described embodiment(s) of the disclosure without departing substantially from the spirit and principles of the disclosure. All such modifications and variations are intended to be included herein within the scope of this disclosure and the present disclosure and protected by the following claims.

What is claimed is:

1. A symmetric transmit opportunity (TXOP) truncation method comprising:

receiving a first frame at a first station that truncates a TXOP around a second station that transmitted the first frame;

determining an estimated distance between the first station and the second station based on one or more characteristics of the received first frame; and

responsive to a determination that the coverage areas for both the first station and the second station do not substantially overlap, sending a second frame from the first station that truncates the TXOP around the first station.

2. The method of claim **1**, further comprising sending an acknowledgement (ACK) frame before sending the second frame.

3. The method of claim **1**, wherein the first frame is sent at a non-basic rate, and the second frame is sent at a basic rate.

4. The method of claim **1**, wherein sending the second frame comprises sending the first frame with an address of an access point (AP).

5. The method of claim **4**, wherein the address of the AP comprises an address in a BSSID field of the first frame.

6. The method of claim **1**, wherein the first frame is a CF-end frame.

7. The method of claim **1**, further comprising sending a frame that includes an indicator of an end of a TXOP.

8. The method of claim **7**, wherein the indicator is a trigger to truncate the TXOP.

9. A symmetric transmit opportunity (TXOP) truncation station comprising a processor configured to:

receive a frame that truncates a TXOP around a first station that transmitted the frame;

determine an estimated distance between the second station and the first station based on one or more characteristics of the received frame; and

responsive to a determination that the coverage areas for both the first station and second station do not substantially overlap, send a second frame from the second station that truncates the TXOP around the second station.

10. The station of claim **9**, wherein the processor is further configured to send an acknowledgement (ACK) frame before sending the second frame.

11. The station of claim **9**, wherein the first frame is sent at a non-basic rate, and the second frame is sent at a basic rate.

12. The station of claim **9**, wherein the processor is further configured to send the second frame by sending the first frame with an address of an access point (AP).

13. The station of claim **12**, wherein the address of the AP comprises an address in a BSSID field of the first frame.

14. The station of claim **9**, wherein the first frame is a CF-end frame.

15. A non-transitory, computer-readable medium having instructions stored there-on for performing a symmetric transmit opportunity (TXOP) truncation between a first station and a second station, the instructions comprising:

instructions for receiving a first frame at a first station that truncates a TXOP around a second station that transmitted the first frame;

instructions for determining an estimated distance between the first station and the second station based on one or more characteristics of the received first frame; and

instructions for sending a second frame from the first station that truncates the TXOP around the first station responsive to a determination that the coverage areas for both the first station and the second station do not substantially overlap.

16. The computer-readable medium of claim **15**, further comprising instructions for sending an acknowledgement (ACK) frame before sending the second frame.

17. The computer-readable medium of claim **15**, wherein the first frame is sent at a non-basic rate, and the second frame is sent at a basic rate.

18. The computer-readable medium of claim **15**, wherein sending the second frame comprises sending the first frame with an address of an access point (AP).

19. The computer-readable medium of claim **18**, wherein the address of the AP comprises an address in a BSSID field of the first frame.

20. The computer-readable medium of claim **15**, wherein the first frame is a CF-end frame.

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